

Calibrating a Free Space Measurement of the Dielectric Properties of Lint Cotton

Mathew G. Pelletier

USDA-ARS, mpelletier@lbr.ars.usda.gov

**Written for presentation at the
2003 ASAE Annual International Meeting
Sponsored by ASAE
Riviera Hotel and Convention Center
Las Vegas, Nevada, USA
27- 30 July 2003**

Abstract. Currently there is a new influx of cotton moisture restoration systems into the cotton ginning industry. These systems are designed to add moisture back to the cotton immediately before the bale press. As such there is a need to control these systems to regulate the amount of water that is added to the bale. Recent research by the USDA indicates that putting too much water back into the bale can result in a degradation of cotton quality while in long term storage. Today's commercially available sensors are either prohibitively expensive or do not provide a method by which to determine the final cotton bale moisture content. Recent research by the author has demonstrated a new free space microwave sensor that looks promising as a low cost method of measuring bale moisture. What is now required is a rapid method to calibrate the system for a commercial deployment of this sensor. To date, little research is available that details the accuracy of commercially available hand-held moisture sensors when used with flash moisture restoration systems. This paper examines both a commercially available resistance based hand-held moisture sensor as well as a new microwave hand-held prototype of the author's design. Both systems are evaluated for accuracy and suitability and use with flash moisture restored cotton lint.

Keywords. Dielectric properties, cotton, microwave, calibration, calibrating

Introduction

In recent years, it has been shown that cotton moisture restoration systems that put moisture back into the cotton immediately before the bale press, can dramatically reduce the force required to press the bale. This force reduction in turn translates into less stress on the bale press system leading to less breakage and down time. The industry is now embracing this new technology (Nelson and Turner, 2003). As such there is a need to control these systems to regulate the amount of water that is added to the bale. Recent research by the USDA (Anthony, 2003) indicates that putting too much water back into the bale can result in a degradation of cotton quality while in long term storage. This can result in the textile mill returning the bales back to the ginner.

Today's commercially available sensors are either prohibitively expensive or do not provide a method by which to determine the final cotton bale moisture content. Recent research by the author has demonstrated a new free space microwave sensor that looks promising as a low cost method of measuring bale moisture (Pelletier, 2003). Other research is also being conducted into alternative low cost ways to measure the bale moisture. For this research to take commercial viability depends in part on what the commercial costs of installation is going to be. If an elaborate calibration study is required to setup the system, then this is going to dramatically affect the cost. Currently, the standard protocol for moisture evaluation of a sensor involves catching numerous can samples just before the bale press box and then later gravimetric drying of can samples (Anthony and Byler, 1997)(Shepard, 1972). This process is time consuming and labor intensive. Ideally to reduce the costs of installation, a rapid method to calibrate the system for a commercial deployment of these sensors is required.

To date, the research into the development or the reliability of a moisture sensor, has always relied on pre-conditioning of the cotton samples over a minimum of 2-3 days in controlled environment chambers, over salt solutions or over glycerin solutions (Byler and Anthony, 1995)(Byler, 1998)(Mangialardi and Griffin, 1971). As all of this research has been directed to the use of resistance methods on conditioned cotton, little is known about how well this type of measurement will work on cotton that has been flash conditioned in a moisture restoration system. It has been the authors experience that cotton that comes out of these systems is not uniformly conditioned. The lint is noticeably non-uniform in moisture content with dry and wet spots occurring within the same sample. Thus, the accuracy of commercially available hand-held moisture sensors when used with flash moisture restoration systems is unknown. In 1998 Byler, reported that with modern electronics the resistance measurement provides a modestly accurate and low cost method to evaluate moisture in cotton gins. This research seeks to establish how well a commercially available resistance based hand-held moisture sensor will work when it is used in conjunction with a flash moisture restoration system. In addition to the commercial resistance sensor, a new microwave based hand-held prototype of the author's design will also be evaluated. Both systems are evaluated for accuracy and suitability for use as a calibration instrument for bale moisture sensors that are inevitably being used in conjunction with a flash moisture restoration system.

Methods and Materials

A measurement protocol was designed to replicate obtaining resistant meter readings on lint samples that are to be obtained at the lint slide shortly after flash conditioning by a rapid moisture restoration system. A system was constructed to deliver dry humid air so as to avoid putting water droplets onto the lint samples. In order to accomplish this a low pressure steam generation system was constructed with the outlet from the steamer set at 5 lbs. of pressure. A batch basket was setup over the outlet along with a cover plate over the outlet to protect the bottom screen of the batch basket from water drops emanating out of the steam outlet port. The cotton lint was then flash conditioned in this basket to varying levels of moisture ranging from 10%-21% moisture content (dry basis).

The lint samples were then removed and immediately weighed on a precision balance, and then placed into the hand-held resistance and microwave sensor to obtain sensor readings. Each reading was replicated three times so as to obtain moisture measurements of three different locations on the lint sample. The resistance sensor was utilized in accordance with the manufactures suggested methods and the hand-held microwave sensor utilized a fixed weight to apply the same pressure to each sample before each reading.

As the cotton was drying throughout this process, by repeating the entire procedure, a dry down curve was obtained for each lint sample yielding moisture readings ranging from 21% down to 4-5% moisture thereby creating a dry down curve with associated balance and sensor readings for each lint sample. After the final measurement for each lint sample, the sample was then analyzed for gravimetric moisture at the final moisture content using standard gravimetric measurement practices (Shepard, 1972). After completion of the analysis for the final moisture content, the precision balance readings were utilized to obtain the gravimetric moisture content for each sensor reading along the entire dry down curve for each of the replicated lint samples.

Results and Discussion

During the process of obtaining the sensor readings it was noticed that each of the samples were of non-uniform moisture content. In order to examine this further, the results were compared between the individual readings to the results where the three replicate readings were averaged. Figure 1 details an example dry-down curve of a very wet sample without averaging of the replicate readings (all of the individual readings). The first obvious point of this figure is the results are very poor. A closer look also reveals that the manufacturers slope is way off for this very wet sample. As the experimental design utilized three replicates for each reading with each replicate taken from a different location on the lint sample, it was decided to try to improve the results by averaging those readings to form a single reading for the lint sample at that moisture content. Figure 2 details this averaging of the three replicate readings.

The results are a noticeable improvement in both the coefficient of determination as well as a reduction in the standard error. As this test had also indicated that the slope was very different from the manufacturers, it was decided to condition the cotton to a lower initial moisture content to see if the altered slope was due to the presence of surface water. As the averaged readings were producing the best results, all of the lint sample dry down curves were combined with the replicates averaged for the remainder of the test analysis.

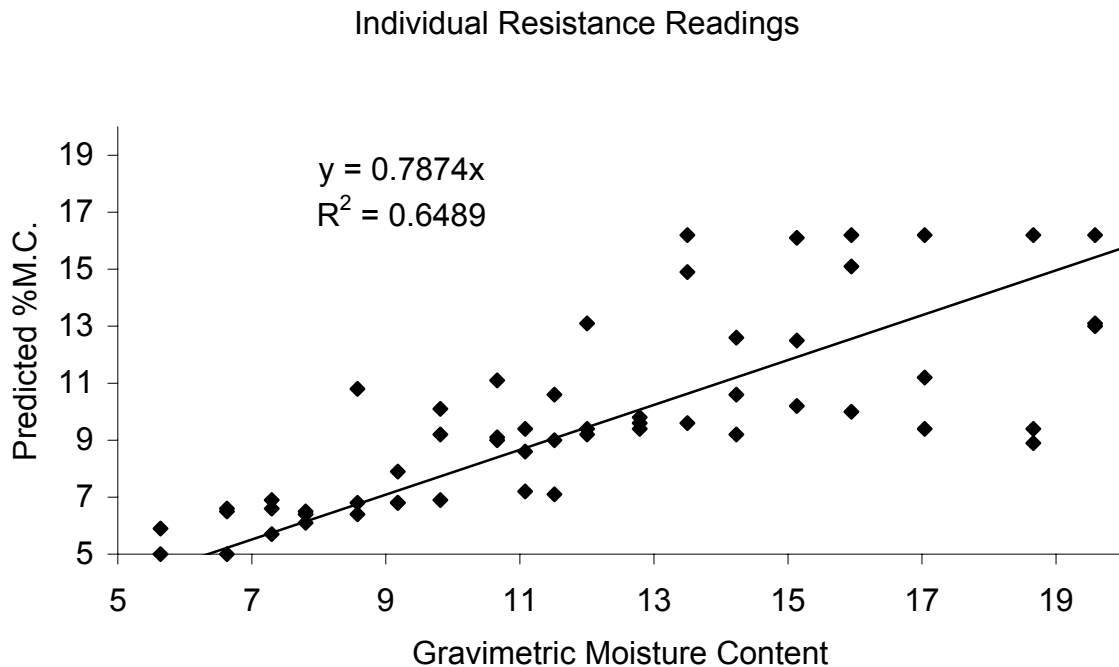


Figure 1. The resistance meter's accuracy when compared to oven gravimetric readings when the meter is used in conjunction with flash conditioned cotton. Flash conditioned cotton is what moisture restoration systems provide. This is the result from the readings for a single lint sample that were taken as the sample was drying out.

Averaged Replicated Resistance Readings

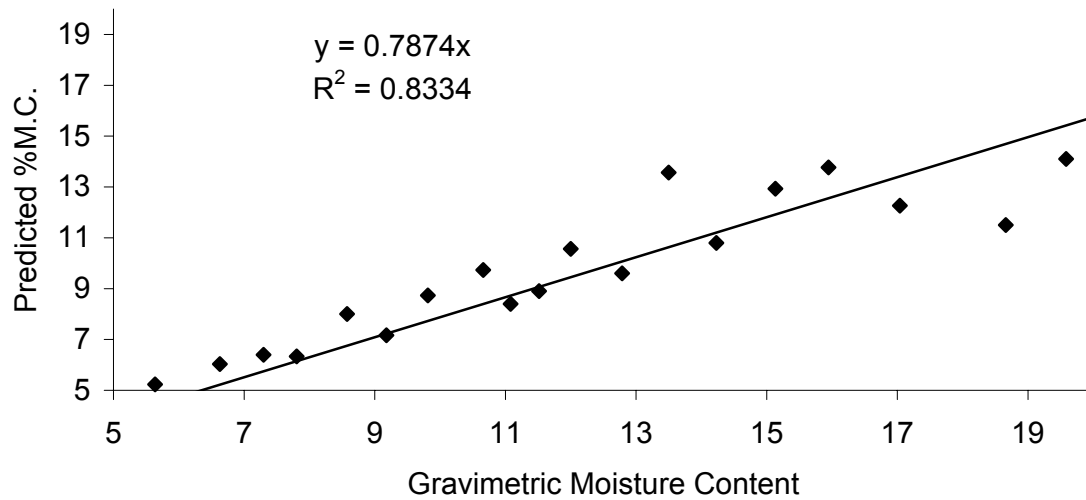


Figure 2. The resistance meter's accuracy of replicated readings when compared to oven gravimetric readings when the meter is used in conjunction with flash conditioned cotton. The difference between figure 1 and figure 2 is that the results for this figure were obtained by taking multiple readings of the lint sample from different locations of that sample so as to obtain an average moisture reading of that sample. This technique results in a dramatic improvement over the normal practice.

The results of the complete data set for the revised experiment is shown in figure 3 for the resistance sensor and in figure 4 for the microwave sensor. In looking at figure 3 it becomes very apparent that the resistance sensor does an increasingly poorer job as the moisture content increases. While the manufacturer's specification state the device is accurate through to 16% moisture on normal cotton that is at moisture equilibrium, it clearly is not the case for flash conditioned cotton. It also leaves one wondering if we can trust the meter on conditioned cotton as well, however we have not tested that here. However, below 9% the device is working well with little change in the slope of the calibration. In addition the results indicate that the accuracy of the instrument is $\pm 1.5\%$ moisture content with a 95% confidence in the reading.

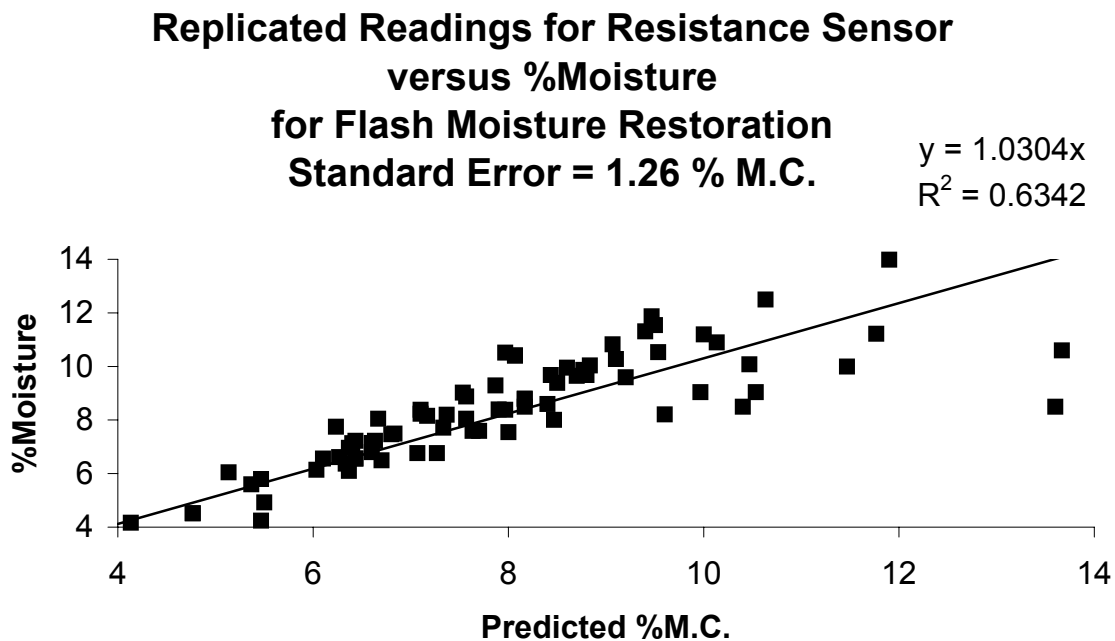


Figure 3. The resistance meter's accuracy of replicated readings when compared to oven gravimetric readings when the meter is used in conjunction with flash conditioned cotton.

These results indicate that if the installation crew takes multiple readings of each lint sample and only utilizes the resistance sensor below 8-9% then they can rely on the averaged reading being within 1.5% of the true moisture content. This is encouraging as a simple change in the way the device is used can provide a rapid estimation of the moisture content of the incoming cotton. This should at least allow a ginner and bale-moisture-sensor installers to spot check their bale moisture sensors for a rough reading. If this technique is combined with the inherent ability of the moisture restoration system to varying the moisture content over several moisture percentage points, then by ramping the moisture from dry to wet while taking resistance readings, the set point accuracy of the sensor should become apparent to the user.

The next analysis is in regards to the performance of an experimental hand-held microwave moisture sensor. The microwave moisture sensor is designed to utilize the same electronics and the same basic algorithm that the free space microwave bale moisture sensor uses. The thought was to utilize the small device as a field instrument to determine instrument accuracy. In figure 4 we detail the results from the test. The results indicate that the instrument has a uniform standard error of 1.27% across the entire moisture content range from 5-15% moisture. This is encouraging as it's out performing the resistance sensor at the higher moisture contents. This suggests it might also be suitable for use inside a moisture restoration system where the moisture contents are very high with lots of free water on the surface of the sensor.

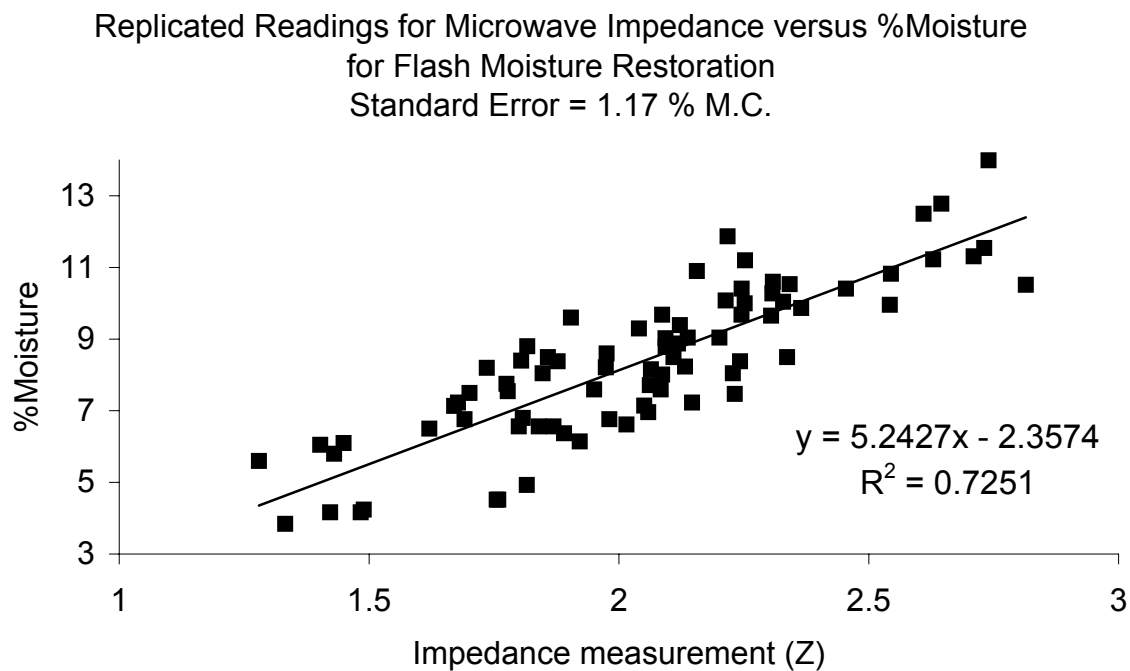


Figure 4. The resistance meter's accuracy of replicated readings when compared to oven gravimetric readings when the meter is used in conjunction with flash conditioned cotton.

Conclusion

The research indicates that for cotton below 8-9% moisture content (dry basis) that has been flash conditioned with a moisture restoration system, a resistance sensor when utilizing a simple protocol of averaging three readings that are composed of readings from different portions of the lint sample, can be used to provide an accuracy of +/- 1.5% moisture content with a 95% confidence in the reading. While this level of accuracy is less than expected, it was shown to have the same slope as the manufacturers calibration (to within 3%). Over the full range of the test and still within the limits of the instrument as detailed in the manufacturing specifications, the instrument only produced a coefficient of determination of $r^2=0.634$ with an accuracy of +/- 3.02 % moisture content (95% confidence).

The research also indicates that the hand-held microwave sensor provides a sensing prediction capability with a standard error of 1.17% moisture across the full range of the experiment. The coefficient of determination for the test resulted in an $r^2=0.725$, with an accuracy of +/- 2.34% moisture content with a 95% confidence in the reading. Further

work is required to determine if the sensor performance will improve if used with conditioned cotton.

References

Anthony, W.S. 2003. The impact of excess moisture in the bale on fiber quality. Proceedings of the Beltwide conference (1) 746-760.

Anthony, W.S. and R.K. Byler 1997. Estimation of Bale Moisture Content with a Malcam MMC-4000. Proceedings of the Beltwide conference (2) 1574-1576.

Byler, R.K. and W.S. Anthony, 1995. Development of a moisture sensor for gin use. Proc. Beltwide Cotton Conf., San Antonio, TX. 4-7 Jan. 1995. Natl. Cotton Counc. Am., Memphis, TN.

Byler, R.K., 1998. Resistivity of cotton lint for moisture sensing. Trans. ASAE 41 (3): 877-882.

Mangialardi, G.J. and A.C. Griffin. 1971. Electrodes for continuously measuring cotton moisture content at ginneries. USDA-ARS Production Research Report 128. Washington, D.C.: USDA.

Nelson L. and N. Turner 2003. Cotton Moisture control in West Texas. Proceedings of the Beltwide conference (1) 742-745.

Pelletier, M.G. and M. Gvili 2003. Microwave measurement of cotton lint moisture. Proceedings of the Beltwide conference (1) 761-762.

Shepherd, J.V. 1972. Standard Procedures for Foreign Matter and Moisture Analytical Tests used in Cotton Ginning Research. USDA Agricultural Handbook No. 422. Washington D.C.: USDA.